PROCEEDINGS OF SCIENCE

A Real–Time Digital Signal Processing Readout System for the PANDA Straw Tube Tracker

P. Kulessa*[a], M. Drochner [b], A. Erven[b], W. Erven[b], L. Jokhovets[b], G. Kemmerling[b], H. Kleines[b], H. Ohm[b], K. Pysz[a], J. Ritman[b], V. Serdyuk[b], S. v. Waasen[b], P. Wintz[b], P. Wuestner[b]
[a]*Institute of Nuclear Physics PAN (IFJ PAN), Krakow, Poland,*
[b]*Forschungszentrum Juelich (FZJ), Juelich, Germany,*
E-mail: pawel.kulessa@ifj.edu.pl

The PANDA Straw Tube Tracker (STT) with its about 4600 channels (straw tubes) requires a trigger–less real–time readout system providing time information for particle tracking and energy loss information for particle identification through the dE/dx method. The required time and dE/dx resolution is $\sim$1 ns and about 10% respectively. The expected maximal particle rate is 1 MHz per straw tube for innermost tubes layers. Strong variations of signal amplitudes, shapes and rise times require careful optimization of pulse processing and analysis. Additional constraints for the readout system are very limited space for electronics inside the detector, little heat dissipation permitted by the system and the necessary radiation hardness for the components placed directly on the detector. Taking into account all this a readout system is proposed with all electronics placed outside the detector connected with straw tubes directly via coaxial cables used for signal transmission and HV supply. Data will be recorded with sampling ADC's from which the relevant information will be continuous deduced via digital Pulse Shape Analysis (PSA) performed in FPGA's.

52 International Winter Meeting on Nuclear Physics
27 – 31 January 2014
Bormio, Italy

*Speaker.

1. Introduction

In this article a data acquisition system is described which is in preparation for the PANDA STT. It is based on detector signal digitization in sampling ADC's and feature extraction algorithms implemented in FPGA's. First a short overview of the STT (Straw Tubes Tracker) detector [1] is given together with the needed time resolution for particle tracking and energy loss resolution for particle identification. Subsequently, a description of signal forms, available space, cooling and other constraints is given. In next chapter a schematic overview of the system is presented followed by the chapters with presents results obtained in laboratory tests and tests performed with proton beam of COSY Juelich [2].

2. The Straw Tube Tracker (STT) for PANDA experiment

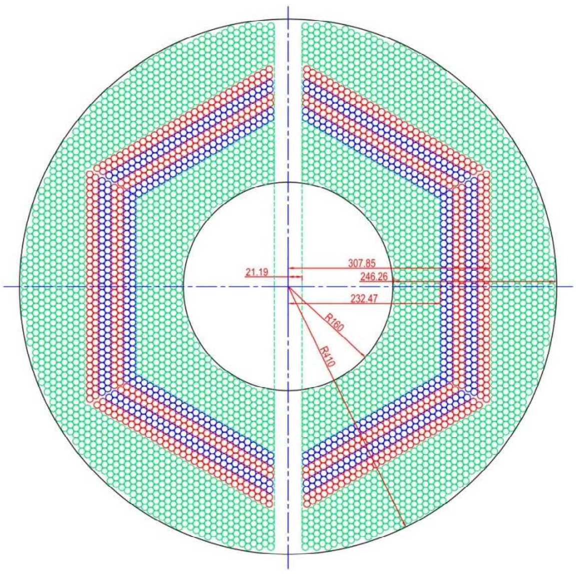

Figure 1: The lateral cut of the Straw Tube Tracker (STT). The green straw layers are axial. The blue/red straw layers are stereo double layers for 3D reconstruction. Each straw has ∼150 cm length and 1 cm diameter. The space between the two halves is reserved for the pellet target. The six hexagonal sectors are well visible.

The Straw Tube Tracker is part of the central tracking system of the PANDA detector [3]. The STT encloses a Micro–Vertex–Detector (MVD) for the inner tracking and is followed in beam direction by a set of GEM–stations. The STT consists of ∼150 cm long drift tubes arranged in 23 to 27 planar layers in a cylindrical volume around the beam axis in six hexagonal sectors. The setup includes 4 stereo double layers for 3D reconstruction, see Fig. 1.

The straws are made of two layers of 12 μm mylar film glued together to 1 cm diameter tubes; the anode is a gold–plated tungsten–rhenium wire with 20 μm diameter. The straw tubes are filled with a Ar CO_2 mixture at 1–2 bar overpressure; high voltage is usually in the range 1750–1950 V. Due to the overpressure the mechanical construction is self supporting and therefore has small material budget (X/X_0 ∼1.2%).

3. Requirements for particle tracking and identification

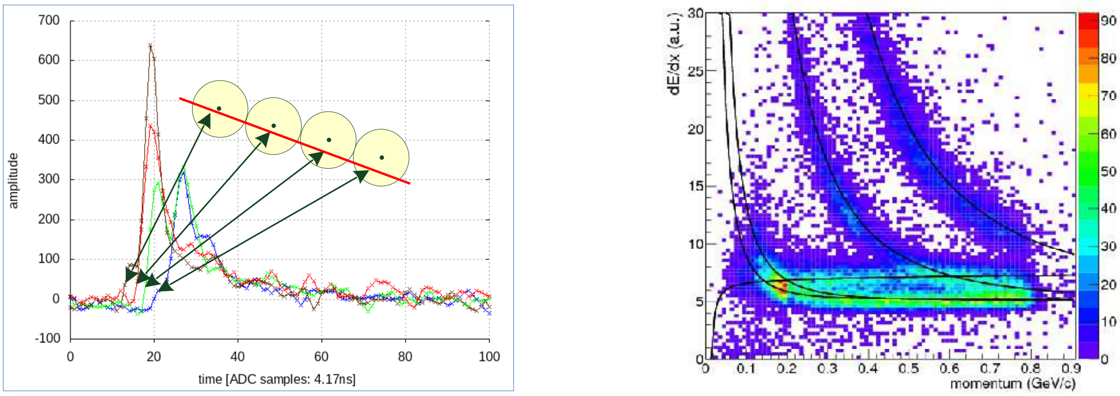

Figure 2: Left: Example of signals induced by the same particle passing through several straws. Right: Particle identification technique, bands corresponds to different particles: e, μ, π, K, p.

In the left part of Fig. 2 the track of a single particle passing several straw tubes is presented. For particle tracking the space position information with an accuracy of $\sim$150 μm corresponds to about 1 ns time resolution for the leading edge of the signal. As one can see in the left part of Fig. 2 increasing distances from tube center lead to increasing delay time of the signal onset. The ends of the signals correspond to ionization clusters induced near the straw tube wall and they are almost the same for all presented tubes.

On the right side of Fig. 2 the particle identification technique based on specific energy loss (dE/dx) is presented [4] which requires the knowledge of the deposited energy and the path length. The deterioration of the particle separation due to the Landau tail in the dE/dx distribution is usually reduced by application of the truncated mean technique [5]. An accuracy of about 10% of the energy deposited in a particle track is needed.

4. Constraints for STT readout system

The most important task of the system is to deduce exact time information from the onset of the signal which is needed both for the tracking as for particle identification. For the latter precise track information is needed since it enters into the path length of the particle.

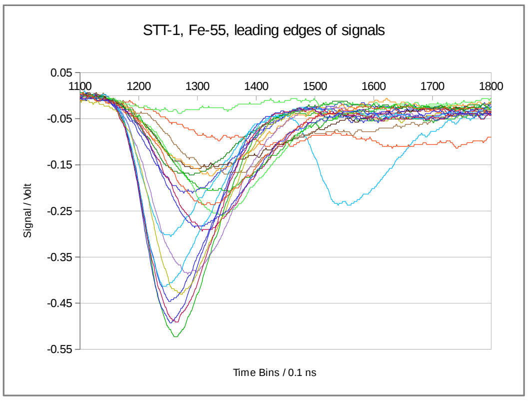

Figure 3: Straw tube signals induced by ^{55}Fe x–rays collected with 240 MHz sampling ADC. The spread of signal rise times and amplitudes are clearly visible.

Even for signals originating from very similar ionization events of an ^{55}Fe x–rays source there is a significant spread in amplitudes and shapes as one can see in Fig. 3. Simple leading–edge technique will suffer from the walk effect due to pulse–height variations. These can largely be compensated by constant–fraction timing as long as the pulse shapes are similar. Signals generated by long particle tracks, however, are superpositions of several components belonging to individual ionization events and have very different shapes, see Fig. 4. In cases where two or more clusters appearing at different times contribute to the leading edge of a signal the constant–fraction technique will fail as in the example shown in the upper right part of Fig. 4.

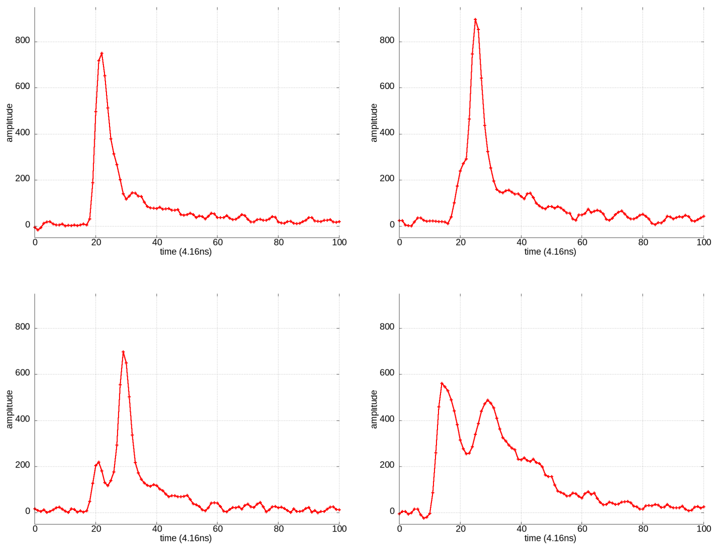

Figure 4: Different signals shapes collected from one straw tube with sampling ADC.

The deduction of the energy loss from a signal of a straw tube measured with the sampling ADC is less dependent on pulse parameters. It requires a good knowledge of the baseline position and integration of the signal over a reasonable time range up to the maximum electron drift time of a tube.

The space reserved for electronics inside PANDA is only ∼15 cm along the axis of the STT. Electronics attached directly to the STT has to have very little heat dissipation and it must be radiation hard because of high luminosity of PANDA and the short distance from interaction point.

5. Proposed readout system

It is proposed that the PANDA STT is read out with a sampling ADC based system where all electronics are placed at a distance of about 12 m from the STT, see Fig. 5. For the system architecture see [6].

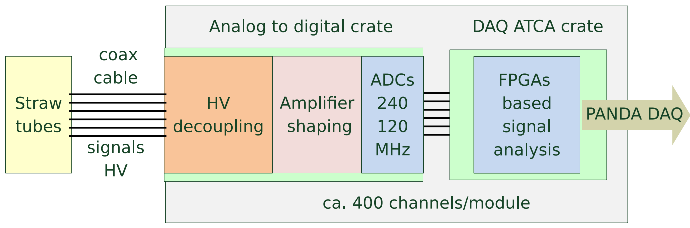

Figure 5: The schematic overview of proposed STT readout system.

The straw tubes are directly connected by coaxial cables to the electronics placed outside the detector. There will be one type of crates housing signal decoupling from high voltage, shaping amplifiers and sampling ADC's. This is followed by an ACTA crate with FPGA's for digital signal processing. It is planned that each board accommodates 400 channels. This will allow corrections based on signals from neighboring straw tubes, for example noise rejection or recognizing signals with small amplitudes.

Placing electronics outside the detector solves radiation hardness and heat problems. Since space near the STT is then needed only for connectors and cables these can be conveniently accommodated.

For the extraction of the starting time of the signal from its rising edge it is foreseen to use the response function of individual ionization clusters for disentangling the signal slope into its components and thus determine t0. For a precise analysis a sufficiently large number of data points along the rising edge is required. This can be achieved by increasing the sampling frequency of the sampling ADC or the shaping time of the amplifier. Here a compromise has to be found including noise considerations for the amplifier and budget limitations for the sampling ADC. Currently sampling ADC's with 120 MHz or 240 MHz together with shaping times of few tens of nanoseconds are under consideration.

The approach of connecting straw tubes with electronics placed several meters away was already successfully used in the WASA detector at COSY Juelich [7] see Fig. 6.

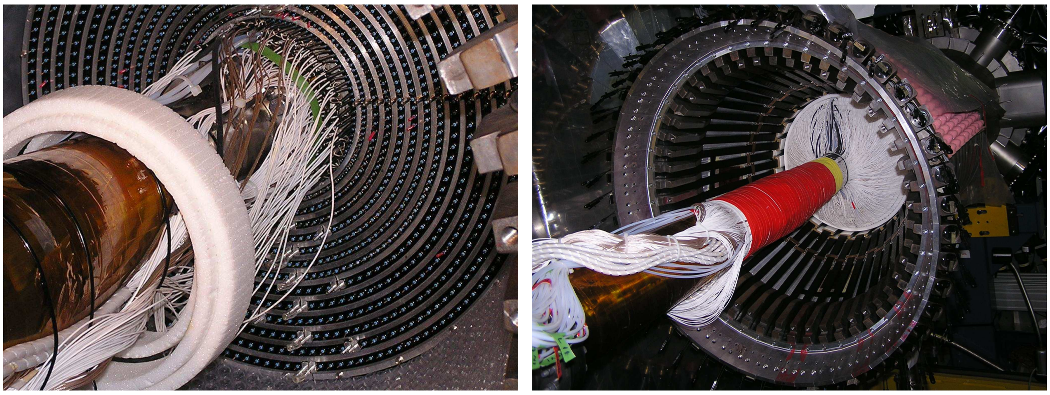

Figure 6: The central tracker of the experiment WASA at COSY Juelich. The straws are coupled with 5 m long coaxial cables for HV supply and signal transmission to electronics placed in a remote position. Left: partially cabled, Right: fully cabled.

6. Laboratory tests and performance of the system with particle beams

In this section different performance test of the system are presented.

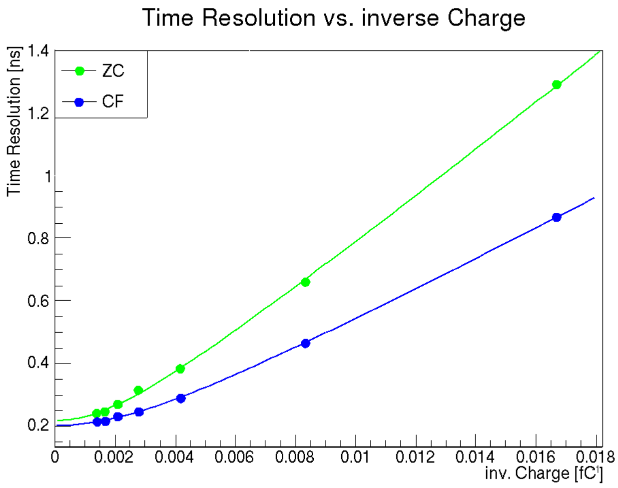

Figure 7: Time resolution for 240 MHz sampling ADC using two different timing methods (CF – constant fraction, ZC – zero crossing extrapolation) as function of the inverse charge.

In Fig. 7 the time resolution of 240 MHz sampling ADC are presented for pulser signals injected with a known charge. Signals with shape and charge similar to physical signals were injected into a straw tube, amplified and sent to the sampling ADC. Two algorithms of time extraction have been tested: constant fraction (CF) and zero crossing extrapolation [8]. Time resolutions near 200 ps were achieved which are close to the FPGA computational accuracy of 1/16 of sampling bin width. This test shows that the intrinsic time resolution of the 240 MHz sampling ADC is sufficient for required time resolution for STT readout.

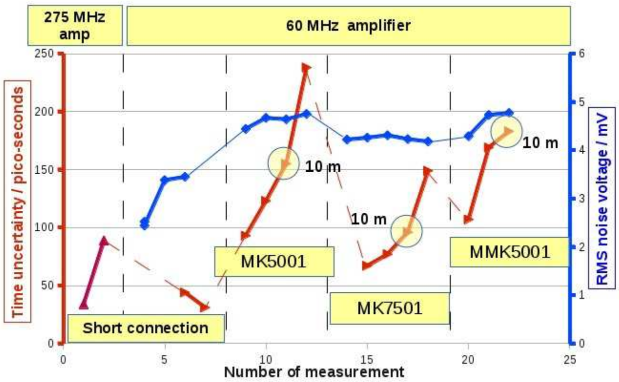

Figure 8: Influence of the length and type of the cable on the timing resolution of a straw tube detector.

The influence of cable length and cable type have been deduced from measured rms noise voltages and signal slopes. Results are presented in Fig. 8. The tests were performed with 60 MHz bandwidth amplifier and oscilloscope. The measurement obtained for 10 m long cables are marked with circles. They show that a time resolution less than 200 ps can be expected for different cable length ant types, which is far below the required time resolution. These investigations also show that the noise added to the signals by these long cables is negligible.

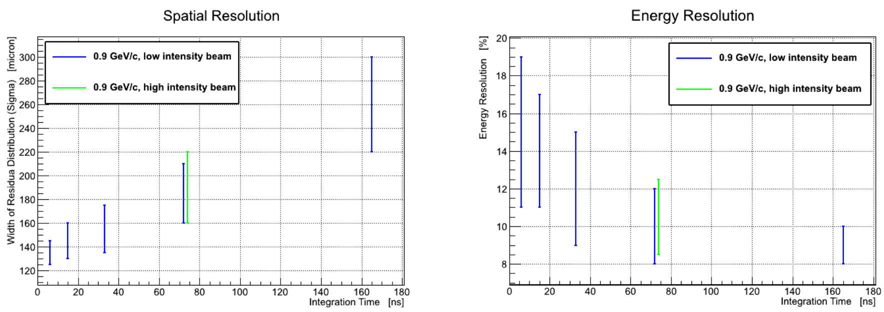

Figure 9: Spatial (left) and energy (right) resolution of a stack of 16 straw tubes versus the integration time of the amplifier. The data were recorded in a proton beam with a 240 MHz sampling ADC. The vertical error bars indicate the range of results for various techniques of data analysis.

In an attempt to investigate the usefulness of simpler and cheaper peak detecting ADC's the feasibility of simultaneous extraction of time and charge from a uniformly shaped signal has been investigated. The signal integration time is expected to have unwanted effects on time and energy resolution. Signals were processed with amplifiers covering a range of shaping times from 6 ns to 160 ns and subsequently recorded with the 240 MHz sampling ADC. The signal arrival time was deduced from the signal crossing of a fixed threshold while the charge was taken from the height of the signal. For energy loss extraction the collected pulses were integrated over the same time range for different amplifier integration times.

As shown in left part of Fig. 9 for signal integrations time below 30 ns a spatial resolution below 150 μm can be achieved. There were no significant differences observed for different proton beam energies. The energy loss resolution improves with increasing integration time; beyond 100 ns no significant changes are observed.

The observations show that only a moderate resolution for time and energy loss can be simultaneously achieved with conventional ADC's using a compromise for the shaping time near 30 ns. For digital pulse processing the lesson can be deduced that integration over the first half of the signal length is sufficient.

7. Summary and outlook

We have shown that a real–time digital signal processing readout system for the PANDA STT is feasible. Raw signals from the straw tubes can be transmitted via cables to remotely placed analog and digital electronics. This gives enormous advantages for the topology of the whole detector system.

The application of sampling ADC's gives full control over all relevant features of the tracking detector. Raw (sampled) signals can be monitored on–line so that the status of each straw tube including the whole electronics chain is visible at any time. Real–time parameter extraction from signals using FPGA's gives precise control over baseline positions and signal levels even under strongly varying operating conditions like high counting rates.

Having full information about every individual signal opens up the possibility of a judgment of the quality of each signal based on its amplitude and shape. Thus, time information can be provided with error bars permitting an improvement of the physics data to be measured due to weighted fitting of particle tracks.

In the next major step towards the final architecture of the read out system for the PANDA STT a newly developed sampling ADC will be employed. This is equipped with modern Kintex 7 FPGA's for implementation of advanced algorithms. Amplifiers are under preparation which permit selection of shaping parameters for optimum performance of feature extraction from the raw signals. Tests with proton and deuteron beams are planned.

Acknowledgments

This work was partially supported by the COSY FFE program.

References

[1] W. Erni et al., *Eur. Phys. J.* A49 (2013) 25

[2] R.Maier *NIM* A390 (1997) 1

[3] C. Schwarz et al., *J. Phys. Conf. Ser.* 374 (2012) 012003

[4] K. Pysz et al., *PoS*, BORMIO2011:011,2011.

[5] P. Kulessa et al., *PoS*, BORMIO2011:010,2011.

[6] L. Jokhovets et al., *IEEE Nuclear Science Symposium and Medical Imaging Conference, and Room-Temperature Semiconductor X-Ray and Gamma-Ray Detectors workshop, Seoul, South Korea, 10/27/2013 - 11/02/2013 8 (2013)*

[7] H.-H. Adam et al., *arXiv:nucl-ex* 0411038

[8] P. Kulessa et al., *PoS*, BORMIO2012:012,2012.